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VALIDATION OF THE MULTI-DOPPLER QUADRATURE CORRELATOR (MDQC). (U)
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TECHNICAL NOTE

VALIDATION OF THE MULTI-DOPPLER
QUADRATURE CORRELATOR (MDQC)

by

Dr. D. B. Doan

Submitted to

Commanding Officer and Technical Director
Naval Undersea Research and Development Center
San Diego Division
San Diego, California 92132

Attn: Mr. Louis Strauss, Code 603

7 January 1970

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1. INTRODUCTION

↙ This report validates and documents the operation of the Multi-Doppler Quadrature Correlator (MDQC). A previous technical note¹ described the analytic technique utilized in the development of the MDQC. ↗

Section 2 of this report describes the method used to validate the results obtained from the MDQC. Included in this section are the expected theoretical values and a summary of the actual results. The computer program used in the validation is found in Appendix A.

Appendices B, C, D, and E contain descriptions and program listings of the special TIMFAX Black Boxes required in order to use the Multi-Doppler Quadrature Correlator.

¹ TRACOR Document No. SD/69-008-U, "A Technique for a Multi-Doppler Quadrature Correlation Processing Scheme," 5 August 1969.



2. VALIDATION OF THE MULTI-DOPPLER QUADRATURE CORRELATOR (MDQC)

The operation of the Multi-Doppler Quadrature Correlator was validated by using the MDQC routine to correlate a linear FM slide. Because of the range-Doppler ambiguity of an LFM pulse, correlation peaks are obtained in all channels. The relative delay, Δt , between adjacent channels depends on the bandwidth, B , and pulse length, T , of the signal, and is given by

$$\Delta t = \Delta f T/B, \quad (1)$$

where Δf is the channel spacing. For the LFM up-slide, which was used in the validation program, the peaks in the up-Doppler channels will occur later than the ones in the zero-Doppler channel. The peaks in the down-Doppler channels will occur earlier.

Since neither the signal nor the reference have been time-compressed, there is no dilation loss involved here. The amplitude of the correlation peaks, relative to the zero Doppler channel, is determined by the overlap loss, and is given by

$$L = 1 - \left| \frac{\Delta t}{T} \right| = 1 - \left| \frac{\Delta f}{B} \right|. \quad (2)$$

The validation program consists of the TIMFAX topology shown in Figure 1. The Black Box, PGEN1, generates an LFM slide from 100 to 200 Hz, sampled at 1000 Hz. The pulse is 1 second long. CORGN1 and CORGN2 generate, respectively, sine and cosine representations of the same LFM signal. The references from the two uses of CORGN are each broken into 7 pieces by the two uses of MSCAT. MSCAT also clips the references, and reformats them into a form suitable for MDQC. The 7 output channels from MDQC are processed through 7 uses of LOCAL and 7 uses of LOCPR to extract and print the maximum value in each channel and the time at which it occurred.

MDQC1 uses an 8 point Fast Fourier Transform to produce 7 Doppler channels. The spacing between the channels is thus 7/8



Hz. The effect of low-pass filtering prior to comb filtering which is inherent in the design of MDQC is given in Equation 12 of Reference 1 as

$$I = \frac{\sin \frac{\omega_o T}{2N}}{\frac{\omega_o T}{2N}} \quad (3)$$

where ω_o is the Doppler offset (in radians/second), T is the pulse length in seconds and N is the number of pieces in the reference. Since the channel spacing is $7/8$ Hz,

$$\omega_o = 2\pi \frac{7}{8} n, \quad (4)$$

where n is the channel number, measured from the zero-Doppler channel. The filter loss on the n th channel is thus

$$I_n = \frac{\sin \frac{\pi n}{8}}{\frac{\pi n}{8}}$$

(Note that this factor can usually be ignored. However, the test case violates the restriction given by Equation 1 of Reference 1, resulting in higher than normal filter loss.)

The results of the validation program are predicted to be as follows:

- (a) The amplitude of the zero Doppler channel for a clipped reference will be equal to the average absolute value of the input signal. Since PGEN1 produces a sinusoid with a peak amplitude of 1, the peak in the zero-Doppler channel will be $2/\pi = .6366$.
- (b) The amplitude of the n th channel will be modified by Equations 2 and 5 and will be



$$R_n = \frac{2}{\pi} \left(1 - \left| \frac{7n}{800} \right| \right) \left(\frac{\sin \frac{\pi n}{8}}{\frac{\pi n}{8}} \right). \quad (6)$$

(c) The time of the peak in the nth channel will be

$$t_n = 1 + \frac{7n}{800}, \quad (7)$$

where $n > 0$ represents the nth up-Doppler channel
and $n < 0$ represents the nth down-Doppler channel.

The results predicted by Equations 6 and 7 are tabulated in TABLE I, together with the actual results obtained from exercising the MDQC routine. The agreement is excellent.

TABLE I
COMPARISON OF THEORETICAL VALUE WITH
COMPUTED RESULTS FROM MDQC

<u>Channel</u>	<u>Measured Amplitude</u>	<u>Theoretical Amplitude</u>	<u>Measured Time</u>	<u>Theoretical Time</u>
-3	.4868	.4861	.973	.9737
-2	.5619	.5631	.983	.9825
-1	.6171	.6149	.991	.9913
0	.6359	.6366	.999	1.0000
1	.6139	.6199	1.008	1.0088
2	.5690	.5631	1.016	1.0175
3	.4957	.4861	1.025	1.0263

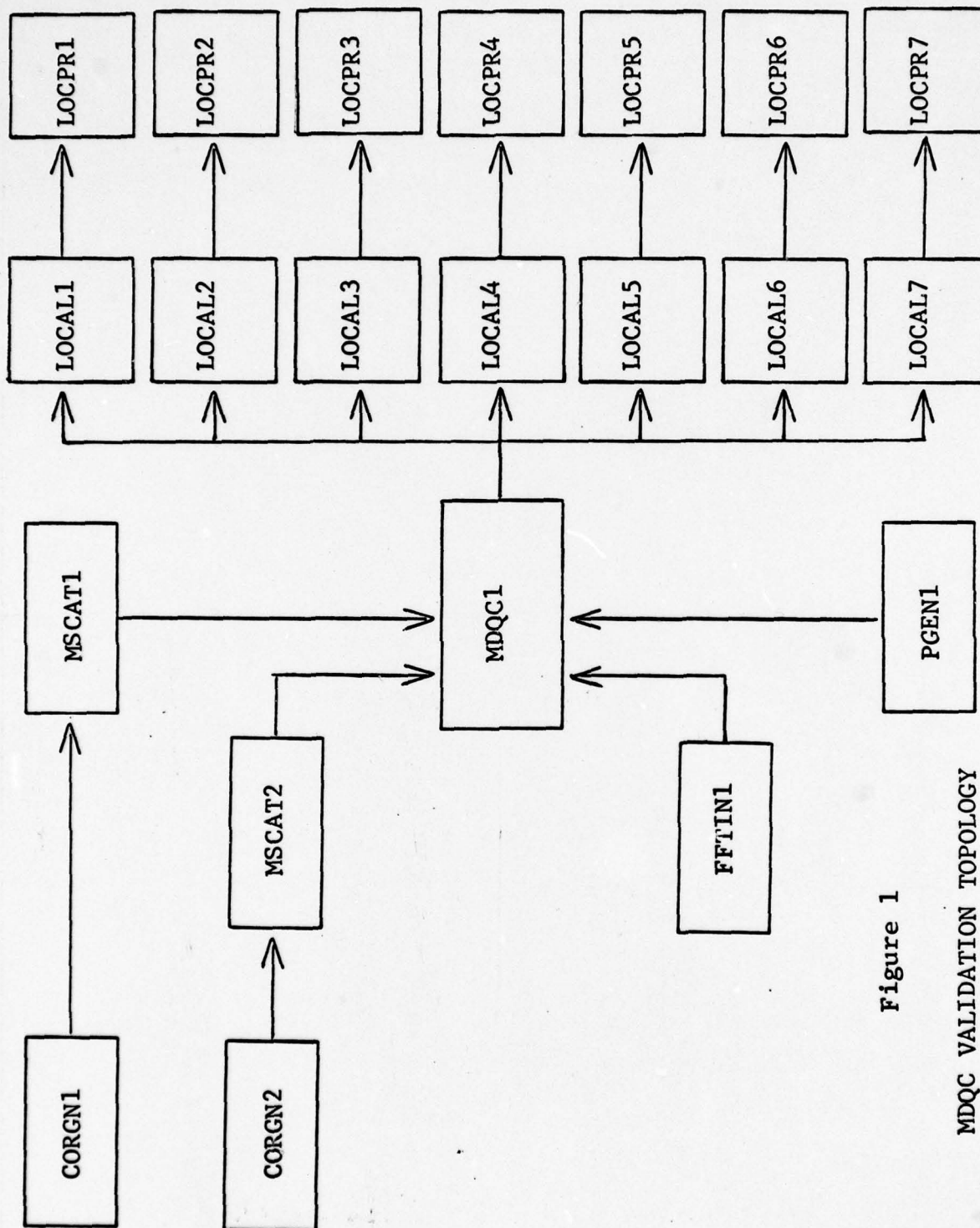


Figure 1
MDQC VALIDATION TOPOLOGY



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APPENDIX A
VALIDATION COMPUTER PROGRAM
FOR MDQC



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APPENDIX A
VALIDATION COMPUTER PROGRAM FOR MDQC
TIMFAX TOPOLOGY

15	CORGN1	
	CORGN2	
	MSCAT1	CORGN1
	MSCAT2	CORGN2
	FFTIN1	
13	PGEN1,A	
	MDQC1,BCDEFGH	MSCAT1,MSCAT2,FFTIN1,PGEN1
	LOCAL1	MDQC1B
	LOCAL2	MDQC1C
	LOCAL3	MDQC1D
	LOCAL4	MDQC1E
	LOCAL5	MDQC1F
	LOCAL6	MDQC1G
	LOCAL7	MDQC1H
11	LOCPR1	LOCAL1A,LOCAL1B
	LOCPR2	LOCAL2A,LOCAL2B
	LOCPR3	LOCAL3A,LOCAL3B
	LOCPR4	LOCAL4A,LOCAL4B
	LOCPR5	LOCAL5A,LOCAL5B
	LOCPR6	LOCAL6A,LOCAL6B
	LOCPR7	LOCAL7A,LOCAL7B



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TIMFAX DATA CARDS

PGEN1=	1000.,	1.,	1.,	100.,	200.,	P24=1000.,	P26=105.
CORGN1=	100.,	200.,	.001,	-1000.			
CORGN2=	100.,	200.,	.001,	-1000.,		P7=1.	
MSCAT1=	7,	1000,	1				
MSCAT2=	7,	1000,	1				
FFTIN1=	8						
MDGC1=	7,	7,	7,	1.0,	1000,	105	
LOCAL1=	3.,	9.					
LOCAL2=	3.,	9.					
LOCAL3=	3.,	9.					
LOCAL4=	3.,	9.					
LOCAL5=	3.,	9.					
LOCAL6=	3.,	9.					
LOCAL7=	3.,	9.					
LOCPR1=	.001,	0.,	1.				
LOCPR2=	.001,	0.,	1.				
LOCPR3=	.001,	0.,	1.				
LOCPR4=	.001,	0.,	1.				
LOCPR5=	.001,	0.,	1.				
LOCPR6=	.001,	0.,	1.				
LOCPR7=	.001,	0.,	1.				
END OF DATA.SET			1				



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TIMFAX PRINTOUT

PC(3) CHANGED TO 8				SCRATCH STORAGE= 772		
	PIECES STORED IN AJ=	7, AI=	7, SCRATCH=	0, TOTAL PIECES=	14,	
MDQC1	N= 143, K= 19, L= 5, S= 1	PIECE 1				
MSCAT1	N= 143, K= 12, L= 4, S= 1	PIECE 2				
MSCAT1	N= 143, K= 20, L= 4, S= 1	PIECE 3				
MSCAT1	N= 143, K= 20, L= 3, S= 1	PIECE 4				
MSCAT1	N= 143, K= 10, L= 3, S= 1	PIECE 5				
MSCAT1	N= 143, K= 16, L= 3, S= 1	PIECE 6				
MSCAT1	N= 142, K= 20, L= 5, S= 0	PIECE 7				
MSCAT1	FIELD STORAGE AVAILABLE= 1005, USED= 172					
MSCAT2	N= 143, K= 20, L= 5, S= 1	PIECE 1				
MSCAT2	N= 143, K= 12, L= 4, S= 1	PIECE 2				
MSCAT2	N= 143, K= 20, L= 4, S= 1	PIECE 3				
MSCAT2	N= 143, K= 20, L= 3, S= 1	PIECE 4				
MSCAT2	N= 143, K= 8, L= 3, S= 1	PIECE 5				
MSCAT2	N= 143, K= 16, L= 3, S= 1	PIECE 6				
MSCAT2	N= 142, K= 19, L= 5, S= 0	PIECE 7				
MSCAT2	FIELD STORAGE AVAILABLE= 1005, USED= 170					



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LOCPR1	CYCLE	1	903, TIME =	.9030SEC.,	S/N =	-16.3759DB,	PK. =	.1518
	PEAK AT WORD							
	PEAK AT WORD		973, TIME =	.9730SEC.,	S/N =	-6.2538DB,	PK. =	.4868
	PEAK AT WORD		1043, TIME =	1.0430SEC.,	S/N =	-10.4048DB,	PK. =	.3018
LOCPR2	CYCLE	1	983, TIME =	.9830SEC.,	S/N =	-5.0073DB,	PK. =	.5619
	PEAK AT WORD							
	PEAK AT WORD		996, TIME =	.9960SEC.,	S/N =	-15.8265DB,	PK. =	.1617
	PEAK AT WORD		1052, TIME =	1.0520SEC.,	S/N =	-13.7684DB,	PK. =	.2049
LOCPR3	CYCLE	1	991, TIME =	.9910SEC.,	S/N =	-4.1931DB,	PK. =	.6171
	PEAK AT WORD							
	PEAK AT WORD		1066, TIME =	1.0060SEC.,	S/N =	-16.1501DB,	PK. =	.1558
	PEAK AT WORD		1061, TIME =	1.0610SEC.,	S/N =	-19.7597DB,	PK. =	.1026
LOCPR4	CYCLE	1	999, TIME =	.9990SEC.,	S/N =	-3.9322DB,	PK. =	.6359
	PEAK AT WORD							
	PEAK AT WORD		1014, TIME =	1.0140SEC.,	S/N =	-16.4843DB,	PK. =	.1499
	PEAK AT WORD		1026, TIME =	1.0260SEC.,	S/N =	-21.3370DB,	PK. =	.0857
LOCPR5	CYCLE	1	940, TIME =	.9400SEC.,	S/N =	-20.7679DB,	PK. =	.0915
	PEAK AT WORD							
	PEAK AT WORD		1008, TIME =	1.0080SEC.,	S/N =	-4.2381DB,	PK. =	.6139
	PEAK AT WORD		1024, TIME =	1.0240SEC.,	S/N =	-17.3109DB,	PK. =	.1363
LOCPR6	CYCLE	1	946, TIME =	.9460SEC.,	S/N =	-14.5449DB,	PK. =	.1874
	PEAK AT WORD							
	PEAK AT WORD		1016, TIME =	1.0160SEC.,	S/N =	-4.8974DB,	PK. =	.5690
	PEAK AT WORD		1032, TIME =	1.0320SEC.,	S/N =	-18.5037DB,	PK. =	.1188
LOCPR7	CYCLE	1	955, TIME =	.9550SEC.,	S/N =	-10.8150DB,	PK. =	.2879
	PEAK AT WORD							
	PEAK AT WORD		1025, TIME =	1.0250SEC.,	S/N =	-6.0962DB,	PK. =	.4957
	PEAK AT WORD		1094, TIME =	1.0940SEC.,	S/N =	-17.3225DB,	PK. =	.1361



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APPENDIX B
MDQC BLACK BOX DESCRIPTION



APPENDIX B

MDQC BLACK BOX DESCRIPTION

PROGRAM NAME: MDQC
NATURE OF WORK: Black Box
PROGRAMMER's NAME: David Doan
DATE: October 25, 1969
COMPUTER LANGUAGE: FORTRAN V

PROBLEM DEFINITION

MDQC is a Multi-Doppler Quadrature Correlator. The Cooley-Tuckey Fast Fourier Transform is used as a comb filter to produce the effect of a number of frequency shifted channels. The output of each filter is processed through an ideal envelope detector.

OPERATING INSTRUCTIONS

1. Topology Card:

The topology card requires four input channels as follows:

MDQCi MSCATj, MSCATk, FFTINl, SOURCEm

The first two fields must be produced by MSCAT; the first one is the real part of the reference, and the second, the imaginary part. The third field, which must be produced by FFTIN, contains the cosine reference required by the Fast Fourier Transform. The time function, indicated above by SOURCEm, is the input signal channel.

2. Data Input:

All P-array entries are fixed point unless noted.

P(1) = Number of outputs (teeth) from comb filter

P(2) = Number of output channels, \leq P(1)



P(3) = Size of Fast Fourier Transform,

$\geq P(1)$

$\geq P(1)$ of MSCAT

= P(1) of FFTIN

= a power of 2

P(4) = Output scale factor, SV = 1.0 (floating point)

P(5) = Estimated length of correlator reference \geq
actual length

P(6) = Estimated input record length \geq actual record
length

P(7) = Number of pieces into which reference is broken.
SV provides automatic transfer of this value from
MSCAT. See Note below. Must equal P(1) of MSCAT.

P(8) = 0 for fixed point time function input

= 1 for floating point time function input.

SV provides automatic transfer of this value
from MSCAT. See Note below. Must equal P(3)
of MSCAT.

NOTE: If the fields from MSCAT are input directly to
MDQC, value for P(7) and P(8) need not be
supplied. If the fields are being read from the
drum or tape, P(7) and P(8) must be supplied.

See Section 8, Program Conditions and limitations for
a further discussion of the P-array values required.

3. Input Fields:

The input fields must be produced by the boxes shown
in (1) above. The topology for generation of the complex refer-
ences should be one or the other of the following to provide for
Doppler shift which increases with channel number.



If the references are directly generated, as for instance with CORGN, then the topology should be

```

05 CORGN1      ← sine wave
   MSCAT1      CORGN1
   CORGN2      ← cosine wave
   MSCAT2      CORGN2

```

03

```

MDQC1      MSCAT1, MSCAT2, FFTIN1, . . .

```

If the references are to be obtained by quadrature heterodyning, the topology should be

```

13 - - -
   PGEN1      ← cosine
   PGEN2      ← sine
   TMUL1      PGEN1, SOURCEn
   TMUL2      PGEN2, SOURCEn
   FLTPL1     FSET1, TMUL1
   FLTPL2     FSET1, TMUL2
   RFEXT1     FLTPL1B
   RFEXT2     FLTPL2B
05 MSCAT1     RFEXT1
   MSCAT2     RFEXT2

```

03 - - -

```

MDQC1      MSCAT1, MSCAT2, FFTIN1, . . .

```

4. Output Fields:

Channel A is used as a scratch field. It should not be referenced by any other Box. It can be overlaid by fields not used in the Section 3 containing MDQC.

5. Input Time Function:

The input time function may be either fixed or floating point. The mode requested is determined by P(8).



6. Output Time Functions:

The output time functions are floating point. $P(2)$ channels are produced. If $P(1) > P(2)$, the channels are block-multiplexed in the following manner:

Channels 1 through $P(2) - 1$ are multiplexed by a factor of

$$M_1 = \text{Int} \left[\frac{P(1) + P(2) - 1}{P(2)} \right] .$$

Channel $P(2)$ is multiplexed by a factor of

$$M_2 = P(1) - (P(2) - 1) \cdot M_1 .$$

Note that some combinations of $P(1)$ and $P(2)$ will cause M_2 to be zero. This situation should be avoided, since extra storage is reserved which will not be used.

Block multiplexing means that a full record (equal in length to the input record) is output for each multiplexed channel, followed by a full record of the next multiplexed channel. This is in contrast to the sample by sample multiplexing used by MPX and DEMPX. The block-multiplexed output must be demultiplexed by BDMPX.

If the output is to be held in floating point, $P(2)$ must be less than or equal to 17.

The first time function output is on Channel B. The Doppler shift associated with each output from the filter is

$$f = \frac{\overline{P(1)}}{P(3)T} \left[n - \text{Int} \frac{P(1)}{2} \right] ,$$

where $\overline{P(1)}$ is the $P(1)$ input to MSCAT, f is the Doppler shift in Hertz, T is the pulse length in seconds, and n is the "tooth" number prior to multiplexing. $P(3)$ in this expression will be a power of 2. If $P(1)$ is even, there will be one more up-Doppler channels than there are down-Doppler channels.



The format of the output time function is as follows:

Channel B	Channel C	Last Channel
tooth 1	tooth $M_1 + 1$	tooth $P(1) - M_2 + 1$
tooth 2	tooth $M_1 + 2$	
tooth 3	tooth $M_1 + 3$	
⋮	⋮	tooth $P(1) - 1$
⋮	⋮	tooth $P(1)$
tooth M_1	tooth $2M_1$	blank

7. Printer Output:

One line of print is always produced:

MDQCn PIECES STORED IN AJ = __, AI = __, SCRATCH = __,

TOTAL PIECES = __, SCRATCH STORAGE = __

This message indicates the allocation of temporary storage within the Box.

If $P(3)$ is not a power of 2, the message

MDQCn $P(3)$ CHANGED TO _____



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will be produced, indicating that P(3) has to be set to the next higher power of 2.

The following messages indicate fatal errors. The run is aborted if any of them appear.

MDQCn UNBALANCED REFERENCES

NO. OF PIECES j,k

T-F MODE 1,m

The number of pieces or the time function mode was not the same for both references.

MDQCn UNBALANCED REFERENCES

SHORT REF LENGTH j,k

NO. LONG REFERENCES 1,m

The length of the two references was not the same.

MDQCn OVERFLOW IN $\begin{smallmatrix} AI \\ PC \end{smallmatrix}$ STORAGE, $\begin{smallmatrix} REAL \\ IMAG \end{smallmatrix}$ PIECE j

LAST REQUEST = k, 1 available

Probably caused by too small a value for P(6), the estimated record length.

MDQCn P(3) = ____ IS ILLEGAL

is produced if $P(3) < P(1)$

MDQCn INCREASE P(5) BY AT LEAST ____

P(5) is less than the total length of the reference supplied.

MDQCn PARAMETER ERROR

EXPECTED PIECES = ____, REAL = ____, IMAG = ____

EXPECTED MODE = ____, REAL = ____, IMAG = ____

P(7) is not equal to P(1) of MSCAT or

P(8) is not equal to P(3) of MSCAT.



MDQCn WRONG FFTIN FIELD
_____ EXPECTED, _____ SUPPLIED

P(3) does not agree with P(1) of FFTIN

THE FIELD FROM _____ OR _____
IS AN ILLEGAL INPUT TO MDQCn UNLESS P(7) AND
P(8) ARE MANUALLY SET.

If the references are recorded on tape or drum, the
parameters P(7) and P(8) must be supplied in the data input.
If they are not supplied, the first two input fields must be
supplied directly from MSCAT.

The following diagnostics were included for check-out
purposes and should not occur:

MDQCn CORR RECORD TOO LONG, PIECE _____
MDQCn REFERENCE ERROR, I = _____
NRR = _____, REALF = _____
NIR = _____, IMAGF = _____

ERROR, REFERENCE LENGTH SUPPLIED TO MDQCn IS SMALLER
THAN THE LENGTH OF THE REFERENCE SUPPLIED

8. Program Limitations or Conditions:

MDQC must be in Section 3.

The parameters for MDQC and MSCAT are as follows:
(P-array values are for MDQC, unless indicated by an over-score.
Over-scored values are for MSCAT.)

- a. Determine the maximum Doppler shift, f_{max} , from
other data known about the problem (relative
velocities, range of interest, etc.). This value
may not exceed



$$f_{\max_1} = \frac{.89 f_o}{BT} \quad \text{for 1 dB dilation loss, or} \quad (1)$$

$$f_{\max_3} = \frac{1.59 f_o}{BT} \quad \text{for 3 dB dilation loss,} \quad (2)$$

where f_o is the center frequency of the signal in the water, B is the bandwidth, and T is the pulse length.

- b. The number of pieces is limited by

$$\overline{P(1)} \geq 4 f_{\max} T. \quad (3)$$

- c. The frequency resolution is given by

$$\Delta f = \frac{\overline{P(1)}}{P(3) T}. \quad (4)$$

To minimize splitting loss,

$$\Delta f \leq \frac{1}{2T}, \text{ or} \quad (5)$$

$$P(3) \geq 2 \overline{P(1)}. \quad (6)$$

- d. $P(3)$ must be a power of 2.
e. Juggle $\overline{P(1)}$ and $P(3)$ to satisfy Equations (3) and (6), and to provide a convenient value of Δf .
f. The total number of outputs teeth is then

$$P(1) = \frac{2 f_{\max} T P(3)}{\overline{P(1)}} + 1. \quad (7)$$



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The input references must be constructed in accordance with the description in Section 3, above. Otherwise, the sign of the Doppler shift may be changed.

WARNING: If $P(1)$ and $P(2)$ are such that the time function outputs are multiplexed, the outputs must be demultiplexed by using BDMPX before writing the output to tape or drum. This requirement exists because the output record length from a tape - or drum - read Box is not necessarily the same as the record length at the input to the tape - or drum - write Box. Under these conditions, the subsequent demultiplex operation will be hopelessly confused.

9. Storage:

2771_8 or 1529_{10} words

10. Subroutines Referenced:

CORR2, CORR3, FIXTST, FLTTST, TWOPOW, BBNAME, PVAL, CALSAL, CTFFT, EREXIT, NPRT\$, NI01\$, NI02\$, SQRT, NERR3\$, CBNAME.

PROCESSING METHOD

MDQC is a digital simulation of the type of correlator in which a comb filter follows the multiplier. The general arrangement of such a correlator is shown in Figure 1.

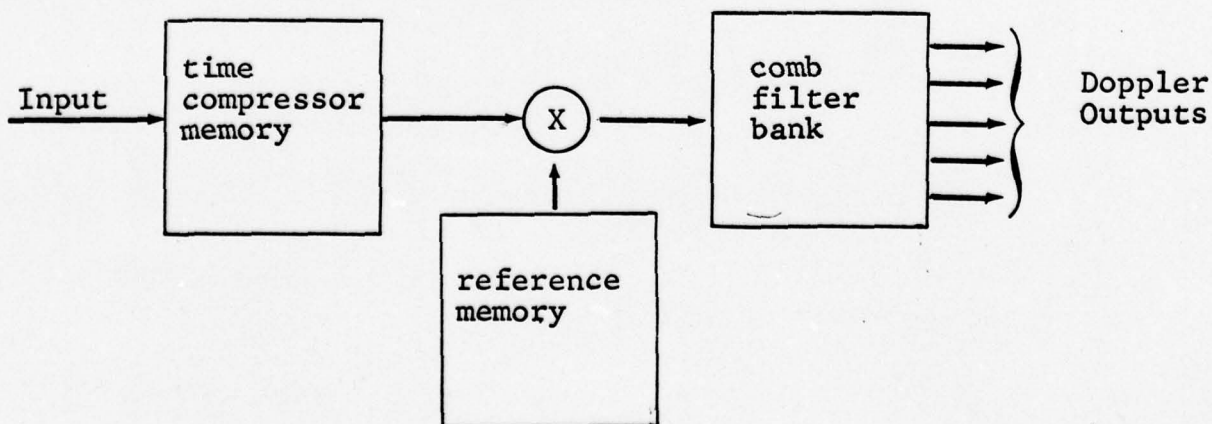


Figure 1

There are two problems in directly simulating the simple method shown in Figure 1. The sampling rate at the input to the comb filter, which is equal to the input sampling rate times the time compression factor, is extremely high. This makes simulation of the filter very time consuming. The method shown is unable to distinguish between positive and negative Doppler, since the pass band of an ordinary filter depends only on the absolute value of the frequency.

These problems are solved in the following way:

- (1) The reference is replaced by a quadrature (complex) reference.
- (2) The multiplier is followed by an "integrate-and-dump" low pass filter.
- (3) The comb filter is simulated by using the Fast Fourier Transform (FFT).

This arrangement is shown in Figure 2.

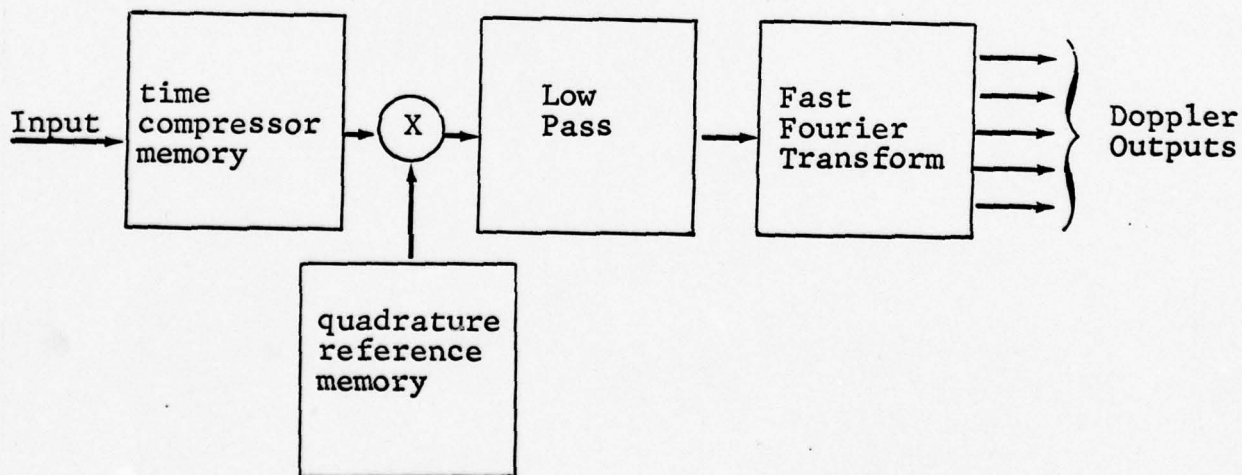


Figure 2



The integrate-and-dump low pass filter greatly reduces the sampling rate at the FFT ("comb filter"), thus reducing the running time. The use of a quadrature reference in combination with the Fast Fourier Transform provides a method for retaining Doppler sense.

Mathematically, the Multi-Doppler Quadrature Correlator consists of the evaluation of the equations given below.

The output of the low pass filter is given by

$$I_n(k) = \frac{N}{K} \sum_{m = \frac{Kn}{N}}^{\frac{K(n+1)}{N}} X_{k+m} r_m, \quad (1)$$

where N = the number of pieces into which the reference is broken

K = the number of samples in the complete reference

X_k = the signal input (real)

and r_m = the complex reference.

The output of the comb filter is given by

$$\rho(k, \ell) = \left| \frac{1}{N} \sum_{n=0}^{N_0-1} I_n(k) e^{-j \frac{2\pi \ell n}{N}} \right|, \quad (2)$$

which is just the discrete Fourier Transform of $I_n(k)$. N_0 is a power of 2, greater than or equal to N .

The parameter, k , is the sample number of the output time function. The parameter, ℓ , is the Doppler parameter. It is related to the Doppler shift at the center frequency by



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$$f = \frac{\epsilon N}{TN_0} , \quad (3)$$

where T is the length of the pulse, and ϵ may be either positive or negative.

The absolute value indicated in Equation (2) performs the function of an ideal envelope detector. No further rectification or averaging is required.

For a more complete mathematical treatment of this process, see D. B. Doan, "A Technique for a Multi-Doppler, Quadrature Correlation Processing Scheme," TRACOR Document No. SD/69-008-U, August 1969.



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APPENDIX C
MDQC PROGRAM LISTING



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APPENDIX C

MDQC PROGRAM LISTING

```
SUBROUTINE MDQCO (N,P)
  DIMENSION P(1),REALF(1),IMAGF(1),AI(1),COREF(1),PC(1),IOUTT(1),
1  NOUT(1),AJ(1),NAME(2),JNAME(2),KNAME(2)
  IMPLICIT INTEGER (A-Z)
  REAL B, AI, AJ, PC, COREF, Z
  PARAMETER PTQ=8
  DEFINE Q(I)=P(I+PTQ)
C      THE VARIABLE Q(I) IS THAT PORTION OF THE P-ARRAY USED
C      FOR INTERNAL SCRATCH STORAGE
  DEFINE AA1(I)=AI(I)
  DEFINE AAJ(I)=AJ(I)
  DEFINE PPC(I)=PC(I)
  EQUIVALENCE (NRR,NAME(1)), (NIR,NAME(2))
  EXTERNAL CORR2, CORR3
  N=13
  P(4)=800L(1.0) @ STD VALUE FOR SCALE FACTOR
  P(7)=-1 @ SV FOR AUTOMATIC
  P(8)=-1 @ SV PARAMETER TRANSFER
  RETURN
  ENTRY MDQCI (P,INPF,INPT,KINPT,LAG,IOUTF,ISIZE,IOUTT,KOUTT,A,B)
  CALL FIXTST (P(1),P(3))
  CALL FLTST (P(4),P(4))
  CALL FIXTST (P(5),P(8))
  NCT=TWOPOW (P(3), 5720) @ IS P(3) A POWER OF 2
  IF(NCT .EQ. P(3)) GO TO 5 @ YES
  CALL BBNAME (NAME) @ NO, PRINT MSG AND SET TO NEXT HIGHER
  PRINT 1004, NAME, NCT @ POWER OF 2
  P(3)=NCT
5  CALL CBNAME (1,JNAME)
  CALL CBNAME (2,KNAME)
  IF (AND(JNAME(1)-5HMSCAT,-63) .EQ. 0 .AND.
1  AND ( KNAME(1) -5HMSCAT, -63 ) .EQ. 0 ) GO TO 6
  IF (P(7) .GT. 0 .AND. P(8) .GE. 0) GO TO 7 @ JUMP IF NOT AUTO
  CALL BBNAME (NAME)
  PRINT 1012,JNAME,KNAME,NAME
  CALL EREXIT
6  P(7)=PVAL(1,1) @ NO. PIECES FROM REAL REF GENERATOR
  P(8)=PVAL(1,3) @ T-F MODE FROM REAL REF GENERATOR
  IF(P(7) .NE. PVAL(2,1)) GO TO 700 @ ERROR IF REAL AND IMAG
  IF(P(8) .NE. PVAL(2,3)) GO TO 700 @ PARAMS NOT THE SAME
7  IF(P(7) .GT. P(3)) GO TO 720 @ FFT AREA TOO SMALL
  INPF=3
  INPT=1
  KINPT=P(3)
  LAG=P(5) + 55
```



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```
IOUTF=1
Q(2)=(P(1) + P(2) - 1)/P(2) @ OUTPUT MPX FACTOR
B=Q(2)
Q(3)=Q(2) * P(2) @ PIECES WHICH CAN BE STORED IN AJ
NS=2*P(7) @ TOTAL PIECES
LC=P(5)/P(7) @ PREDICTED SHORT REF
LCC=MOD(P(5), P(7)) @ NO. LONG REFS
Q(4)=0 @ COUNTER FOR PIECES IN AI
NRR=0 @ COUNTER FOR AI AREA USED

NIR=0 @ COUNTER FOR AI AREA AVAILABLE
DO 10 I=1,NS @ LOOP TO ALLOCATE STORAGE
IF(1 .LE. Q(3)) GO TO 9 @ JUMP IF IN AJ
NRR=NRR + P(6) @ P(6) IS ESTIMATED INPUT RECORD LENGTH
IF(NRR .GT. NIR) GO TO 15 @ JUMP IF TOO MUCH
Q(4)=Q(4)+1 @ COUNT PIECES IN AI
9 IF(AND(1,1) .NE. 0) GO TO 10
NIR=NIR + LC @ RELEASE AFTER EACH PAIR
IF((1+1)/2 .LE. LCC) NIR=NIR+1 @ INCR FOR LONG REF
10 CONTINUE @ END ALLOCATION LOOP
15 NCT=NS-Q(3)-Q(4) @ PIECES LEFT TO STORE
IF(NCT .LT. 0) NCT=0 @ PREVENT ACCIDENTS
ISIZE=P(7)*108 + P(3)*2 + NCT*P(6) @ SCRATCH FIELD
Q(5)=ISIZE @ SIZE SCRATCH FIELD
CALL BBNAME (NAME)
PRINT 1008, NAME, P(3+PTQ), P(4+PTQ), NCT, NS, ISIZE
Q(4)=Q(4) + Q(3) @ TOTAL PIECES IN AI AND AJ
IOUTT(1)=P(2) @ NO. OUPUT CHANNELS
IOUTT(2)=1 @ MAY BE UNBALANCED
KOUTT=1
A=0
RETURN
ENTRY MDQC2 (P)
Q(1)=1 @ INITIALIZATION FLAG
RETURN
ENTRY MDQC3 (P,KFLG,REALF,IMAGF,COREF,IM,INPT,AI,LAG,PC,JM,
1 IOUTT,AJ,NOUT)
JMC=IM - LAG @ NO. NEW SAMPLES
IF (JMC .GT. 0) GO TO 18
JMC=0
JM=0
GO TO 145
18 IF(Q(1) .NE. 1) GO TO 30 @ SKIP INITIALIZATION
IF(REALF(4) .NE. P(7)) GO TO 760 @ PARAMETER ERROR
IF(REALF(5) .NE. P(8)) GO TO 760 @ PARAMETER ERROR
IF(IMAGF(4) .NE. P(7)) GO TO 760 @ PARAMETER ERROR
IF(IMAGF(5) .NE. P(8)) GO TO 760 @ PARAMETER ERROR
IF(REALF(2) .NE. IMAGF(2)) GO TO 701 @ ERROR IF REAL AND IMAG
IF(REALF(3) .NE. IMAGF(3)) GO TO 701 @ REF LENGTHS ARE NOT EQUAL
NCT=COREF(2) @ CHECK LENGTH OF FFT REF
IF(P(3) .NE. NCT) GO TO 750 @ ABORT IF DOESN'T MATCH
```



```
-----
NS = 2 * P(7) @ TOTAL PIECES IN BOTH REFS
NCT=0 @ P ARRAY POINTER
-----
NRR=7 @ REFERENCE ARRAY POINTER
Z=BOOL(P(4))/FLOAT(REALF(6))
-----
DO 20 I=1,NS
PC(NCT+1)=BOOL(REALF(2)) @ P(1) FOR CORR, REF LENGTH
IF((I+1)/2.LE.REALF(3)) PC(NCT+1)=BOOL(BOOL(PC(NCT+1))+1) @ LONG
PC(NCT+2)=FLOAT(REALF(NRR+1))*Z @ P(2) FOR CORR, SCALE
PC(NCT+3)=BOOL(P(8)) @ P(3) FOR CORR, T-F MODE
CALL CALSAV (1,CORR2,PC(NCT+1)) @ INITIALIZE CORR
IF(AND(I,1).EQ. 0) NRR=NRR + REALF(NRR) + 1 @ INCR REF POINTER
20 NCT=NCT + 54 @ INCR P ARRAY POINTER
Q(1)=0 @ CLEAR INITIALIZATION FLAG
30 LC=LAG - P(7)*REALF(2) - REALF(3) @ BASE LAG VALUE
IF(LC.LT. 55) GO TO 730
NCT=1 @ OUTPUT STORAGE SWITCH
NCP=1 @ P ARRAY POINTER
NRR=7 @ REAL REF POINTER
NIR=7 @ IMAG REF POINTER
NS=P(7) @ NO. PIECES IN EACH REFERENCE
NOCT=1 @ AJ STORAGE POINTER
NICT=1 @ AI STORAGE POINTER
NSCT=P(7) * 108 + 1 @ PC STORAGE POINTER
DO 100 I=1,NS @ BEGIN CORRELATION LOOP
LCC=LC+1
LC=LC + REALF(2) @ ADD REF LENGTH TO LAG
IF(I.LE. REALF(3)) LC=LC+ 1 @ INCR IF LONG REF
IN=JMC + LC @ TOTAL SAMPLES TO CORR
IF(NCT.GT.Q(3)) GO TO 40
CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
5 AJ(NOCT),NC)
NOCT=NOCT + JMC @ INCR AJ STORAGE POINTER
GO TO 60
40 IF(NCT.GT. Q(4)) GO TO 50
CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
5 AI(NICT),NC)
NICT=NICT + JMC @ INCR AI STORAGE POINTER
IF(NICT.GT. LCC) GO TO 702 @ AI OVERFLOW
GO TO 60
50 CONTINUE
CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
5 PC(NSCT),NC)
NSCT=NSCT + JMC @ INCR PC STORAGE POINTER
IF(NSCT.GT. Q(5) - 2*P(3) + 1) GO TO 703 @ PC OVERFLOW
60 IF(NC.GT. JMC) GO TO 706 @ CORR OUTPUT RECORD TOO LONG
NRR=NRR + REALF(NRR) + 1 @ INCR REAL REF POINTER
IF(NRR.GT. REALF(1) + 2) GO TO 740
NCT=NCT + 1 @ INCR STORAGE SWITCH
NCP=NCP + 54 @ INCR P ARRAY POINTER
IF(NCT.GT. Q(3)) GO TO 70
```




```
CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),,N,1,AI,LC,JMC,1,
S  AJ(NOCT),NC)
NOCT=NOCT + JMC @ INCR AJ STORAGE POINTER
GO TO 90
70 IF(NCT.GT. Q(4)) GO TO 80
CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),,N,1,AI,LC,JMC,1,
S  AI(NICT),NC)
NICT=NICT + JMC @ INCR AI STORAGE POINTER
IF(NICT.GT. LCC) GO TO 704 @ AI OVERFLOW
GO TO 90
80 CONTINUE
CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),,N,1,AI,LC,JMC,1,
S  PC(NSCT),NC)
NSCT=NSCT + JMC @ INCR PC STORAGE POINTER
IF(NSCT.GT. Q(5) - 2*P(3) + 1) GO TO 705 @ PC OVERFLOW
90 IF(NC.GT. JMC) GO TO 706 @ OUTPUT RECORD FROM CORR TOO LONG
NIR=NIR + IMAGF(NIR) + 1 @ INCR IMAG REF POINTER
IF(NIR.GT. IMAGF(1) + 2) GO TO 740
NCT=NCT + 1 @ INCR STORAGE SWITCH
100 NCP=NCP + 54 @ INCR P ARRAY POINTER
C  END OF CORRELATION LOOP
NS=2*P(7)-1 @ TOTAL PIECES MINUS 1
NSCT=Q(5) - 2*P(3) @ BASE OF FFT WORKING STORAGE
NF1=NSCT+1 @ LIMITS FOR CLEARING FFT STORAGE
NF2=Q(5)
NICT=P(1) - 1 @ NO. TEETH IN FILTER MINUS 1
NIR=P(1)/2 @ OFFSET FOR NEGATIVE FREQUENCIES
DO 140 I=1,JMC @ SAMPLE LOOP
DO 105 J=NF1,NF2
105 PC(J)=0 @ CLEAR FFT WORKING STORAGE
NCT=NSCT @ INITIALIZE FFT INPUT POINTER
DO 130 J=0,NS @ PIECE LOOP
NCT=NCT + 1 @ INCR FFT INPUT POINTER
IF(J.GE. Q(3)) GO TO 110
PC(NCT)=AAJ(I+J*JMC) @ GET SAMPLE FROM AJ
GO TO 130
110 IF(J.GE. Q(4)) GO TO 120
PC(NCT)=AAI(I+(J-Q(3))*JMC) @ GET SAMPLE FROM AI
GO TO 130
120 PC(NCT)=PPC(I+(J-Q(4))*JMC+P(7)*108) @ GET SAMPLE FROM PC
130 CONTINUE
CALL CTFFT (PC(NSCT+1), COREF(4),P(3),2)
DO 140 J=0,NICT @ OUTPUT STORAGE LOOP
NOCT=J - NIR @ INDEX OFFSET FOR NEGATIVE FREQUENCIES
IF(NOCT.LT. 0)NOCT=NOCT + P(3)
140 AAJ(I+J*JMC)=SQRT(PPC(NSCT+2*NOCT+1)**2 + PPC(NSCT+2*NOCT+2)**2)
C  END OUTPUT LOOP
145 NCT=IOUTT(1)
DO 150 I=2,NCT @ SET NO. OUTPUT SAMPLES
150 NOUT(I-1)=JM
```



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```
NOUT(NCT)=(P(1) - (P(2)-1)*Q(2)) * JMC
RETURN
700 NCT=PVAL(2,1)
NCP=PVAL(2,3)
PRINT 1000, P(7), NCT, P(8), NCP
GO TO 799
701 PRINT 1001, REALF(2), IMAGF(2), REALF(3), IMAGF(3)
GO TO 799
702 NOCT=4HREAL
GO TO 710
703 NOCT=4HREAL
GO TO 711
704 NOCT=4HIMAG
GO TO 710
705 NOCT=4HIMAG
GO TO 711
706 PRINT 1003, I
GO TO 799
710 NRR=NICT-1
NIR=LCC - 1
NICT=2HAI
GO TO 715
711 NRR=NSCT - 1
NIR=Q(5) - 2*P(3)
NICT=2HPC
715 PRINT 1002, NICT, NOCT, I, NRR, NIR
GO TO 799
720 PRINT 1005, P(3), P(7)
730 NCT=55 - LC
PRINT 1006, NCT
GO TO 799
740 PRINT 1007, I, NRR, REALF(1), NIR, IMAGF(1)
GO TO 799
750 PRINT 1009, P(3), NCT
GO TO 799
760 PRINT 1010, P(7), REALF(4), IMAGF(4), P(8), REALF(5),
S IMAGF(5)
GO TO 799
799 CALL SBNAME (NAME)
PRINT 1011, NAME
CALL EREXIT
1000 FORMAT (1X,12X,'UNBALANCED REFERENCES'/' NO. OF PIECES',215/' T-F
SMODE'5X,215)
1001 FORMAT (1X,12X,'UNBALANCED REFERENCES'/' SHORT REF LENGTH',215/' N
SO. LONG REFS',4X,215)
1002 FORMAT (1X,12X,'OVERFLOW IN 'A3,'STORAGE, 'A5,'PIECE',15/' LAST RE
SQUEST='15,' '15,' AVAILABLE')
1003 FORMAT (1X,12X,'CORR RECORD TOO LONG, PIECE',15)
1004 FORMAT(1X,2A6,'P(3) CHANGED TO '14)
1005 FORMAT (1X,12X,'P(3)='14,' IS ILLEGAL FOR '14,' PIECES')
```



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```
1006 FORMAT (1X,12X,'INCREASE P(5) BY AT LEAST '15)
1007 FORMAT (1X,12X,'REFERENCE ERROR, I='15/' NRR='15,, REALF(1)='15/'
      S NIR='15,, IMAGF(1)='15)
1008 FORMAT (1X,2A6,'PIECES STORED IN AJ='15,, AI='15,, SCRATCH='15,'
      S, TOTAL PIECES='15,, SCRATCH STORAGE='15)
1009 FORMAT (1X,12X,'WRONG FFTIN FIELD,'15,' EXPECTED,'15,' SUPPLIED')
1010 FORMAT(1X,12X,'PARAMETER ERROR'/' EXPECTED PIECES='15,, REAL='15,
      S', IMAG='15/' EXPECTED MODE ='15,, REAL='15,, IMAG='15)
1011 FORMAT (1H+,2A6)
1012 FORMAT (' THE FIELD FROM 'A6,A1,' OR 'A6,A1,
1      ' IS AN ILLEGAL INPUT TO 'A6,A1,
2      ' UNLESS P(7) AND P(8) ARE MANUALLY SET. ' )
      END
```




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APPENDIX D

MSCAT BLACK BOX DESCRIPTION



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APPENDIX D

MSCAT BLACK BOX DESCRIPTION

PROGRAM NAME: MSCAT
NATURE OF WORK: BLACK BOX
PROGRAMMER'S NAME: David Doan
DATE: August 25, 1969
COMPUTER LANGUAGE: FORTRAN V

PROBLEM DEFINITION

MSCAT produces a set of partial correlator references from a single input field for use with the Box, MDQC. The technique used by the Black Box, SCAT, is used to provide very efficient clipped-reference correlation.

OPERATING INSTRUCTIONS

1. Topology Card:

The topology card for MSCAT requires one floating point field such as that provided by CORGN or RFEXT.

2. Data Input:

All P-array entries are fixed point.

P(1) = number of pieces into which the reference is to be broken. See Section 8 of the MDQC write-up.

P(2) = length of output field. Initially, P(2) should be equal to the length of the input field. It may be possible to reduce this value to conserve storage. See Sections 5 and 6.

P(3) = 0(SV) for fixed point time function input to MDQC.
= 1 for floating point input to MDQC.

3. Input Fields:

The input field must contain a floating point correlator reference in the format produced by Boxes such as RFEXT or CORGN.

4. Output Field:

The output field contains the count word, and five constants, followed by $P(1)$ subfields, each having the format of the field generated by SCAT. The field is shown below:

word 1	:	N
word 2	:	length of short reference
word 3	:	number of long references
word 4	:	$P(1)$
word 5	:	$P(3)$
word 6	:	total reference length
word 7	:	N_1
word 8	:	} constants and machine instructions as generated by SCAT for piece 1
...	:	
word $N_1 + 7$:	}
word $N_1 + 8$:	
word $N_1 + 9$:	} constants and machine instructions as generated by SCAT for piece 2
...	:	
word $N_1 + N_2 + 8$:	}
...	:	
etc.	:	

5. Printer Output:

One line is printed for each piece of the reference. The format of the line is

MSCATx N = __, K = __, L = __, S = __, PIECE y

where x is the use number, N is the number of samples in this partial reference, K, L, and S are parameters indicating the operating of SCAT (See SCAT write-up and SCAT/CORR process description), and y is the number of the partial reference. Following the above is a line with the following format:

MSCATx FIELD STORAGE AVAILABLE = __, USED = __

The storage available is $P(2) + 5$. The storage used is the total number of words in the output field including the count word.



6. Program Limitations and Conditions:
 - a. Each piece must contain at least 2 samples.
 - b. An error message is produced if the output field is too small and the run is aborted.
7. Storage Requirements:

447₈ or 295₁₀ words.
8. Subroutines Referenced:

SCAT3, FIXTST, CALSAV, BBNAME, EREXIT, NPRT\$, NIO1\$, NIO2\$, NERR3\$.

PROCESSING METHOD

MSCAT breaks the reference supplied in the input field into $P(1)$ pieces. If the input field contains N samples, then there are

$$n = N \bmod P(1)$$

long pieces and $N-n$ short pieces.

The first n pieces have a length

$$t_1 = \text{Int} (N/P(1)) + 1,$$

and the remaining $N-n$ pieces have a length

$$t_2 = \text{Int} (N/P(1)).$$

Each piece is converted to a series of add-subtract commands by SCAT3 (part of the Black Box, SCAT). The outputs from SCAT3 are stored in the output field.



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APPENDIX E
MSCAT PROGRAM LISTING



APPENDIX E

MSCAT PROGRAM LISTINGS

```
SUBROUTINE MSCATO (N,P)
  DIMENSION P(1), REF(1), OUT(1), NAME(2)
  EQUIVALENCE (NS,NAME(1)), (OCT,NAME(2))
  IMPLICIT INTEGER (A-Z)
  REAL REF, SAVE
  EXTERNAL SCAT3
  N=6
  P(3)=0 @ FIXED T-F IS STANDARD
  RETURN
ENTRY MSCAT1 (P,INPF,INPT,KINPT,LAG,IOUTF,ISIZE,IOUTT,KOITT,A,B)
  INPF=1
  IOUTF=1
  ISIZE=P(2) + 5
  CALL FIXTST (P(1),P(3))
  RETURN
ENTRY MSCAT2 (P)
  RETURN
ENTRY MSCAT3 (P,KFLG,REF,OUT)
  NCT=REF(1) @ LENGTH OF REF SUPPLIED
  OUT(2)=NCT/P(1) @ LENGTH OF SHORT REF
  OUT(3)=MOD(NCT,P(1)) @ NO. OF LONG REFS
  OUT(4)=P(1) @ NO. OF PIECES
  OUT(5)=P(3) @ T-F MODE
  OUT(6)=NCT @ TOTAL REFERENCE LENGTH
  P(4)=P(2) @ P(1) FOR SCAT, LENGTH OF REF
  P(5)=1 @ P(2) FOR SCAT, FLOATING POINT FIELD FLAG
  P(6)=P(3) @ P(3) FOR SCAT, T-F FLAG
  NCT=1 @ INPUT FIELD POINTER
  MCT=7 @ OUTPUT FIELD POINTER
  NS=P(1) @ NO. OF PIECES
  DO 10 I=1,NS
    OCT=OUT(2) @ LENGTH OF SHORT REF
    IF(I .LE. OUT(3)) OCT=OCT+1 @ INCR FOR LONG REF
    SAVE=REF(NCT) @ SAVE ORIG CONTENTS OF INPUT FIELD
    REF(NCT)=OCT @ SET REF LENGTH IN FIELD FOR PARTIAL REF
    CALL CALSAV (4,SCAT3,P(4),KFLG,REF(NCT),OUT(MCT))
    PRINT 1000, I @ ADD PIECE NO. TO SCAT MSG
    REF(NCT)=SAVE @ RESTORE INPUT FIELD
    NCT=NCT + OCT @ INCR INPUT POINTER
```




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```
10 MCT=MCT + OUT(MCT) + 1 @ INCR OUTPUT POINTER
   IF(MCT-6 .GT. P(2)) GO TO 30 @ OUTPUT FIELD TOO SMALL, ERROR
   OUT(1)=MCT - 2 @ SET LENGTH OF OUTPUT FIELD
20 NCT=P(2) + 5 @ STORAGE AVAILABLE
   MCT=MCT - 1 @ STORAGE USED
   CALL BBNAME (NAME)
   PRINT 1001, NAME, NCT, MCT
   IF(OUT(1) .LT. 0) CALL EREXIT @ ABORT RUN
   RETURN
30 PRINT 1002
   OUT(1)=-1 @ SET ERROR FLAG
   GO TO 20
1000 FORMAT (1H+,45X,'PIECE',I4)
1001 FORMAT (1X,2A6,'FIELD STORAGE AVAILABLE=',I5,', USED=',I5)
1002 FORMAT (/ ' ***ERROR***')
-----END -----
```